Review: Unbalance Voltage Compensation in an Islanded Microgrid

[1]Neha Narayan Jumde, [2]Prof. Praful Tadse

[1]Reseach Scholar, [2]Assistant Professor
[1,2] Electrical Engineering Department,
[1,2] Ballarpur Institute of Technology, Ballarpur-Chandrapur, Maharashtra, India

Abstract : DGs have been a major component in addressing environmental, technological, and economic concerns throughout the history of power system development. The usage of DGs based on renewable energy supplies has decreased climate change worries substantially. Furthermore, the stability of DGs at consumption sites might provide some of the load from these resources, resulting in lower power transmission system loads and losses.

The rising interest in pooling renewable energy resources in power microgrids poses a significant challenge in terms of power system reliability and control. In the recent decade, the subject of microgrid autonomous control has gotten a lot of attention. For islanded microgrids, a hierarchical control method can be used as the power system control architecture. Various approaches for hierarchical microgrid control have been explored thus far. The most up-to-date main control approaches for autonomous microgrid operation are described in this study.

***Index Terms* – Voltage Control, Islanded Microgrid**

I. INTRODUCTION

A microgrid is described as a controlled entity made up of DGs, loads, power electronic devices, and energy storage systems [7, 8]. When compared to individual DG units, it offers the power system with greater dependability and power quality. It also has the capacity to work in both grid-connected and islanded modes [9]. Microgrids are often used in combination with the electricity system. When a power quality event happens, the power system disconnects from the rest of the distribution system by activating a static switch, and then operates independently. The utility grid offers an exact power-sharing scheme and correct electrical set-points for each DG unit in grid-connected mode. When in islanded mode, the voltage source inverters (VSIs) maintain the microgrid's frequency and voltage to guarantee that the autonomous mode runs smoothly.

The DG units provide appropriate power quality and reliability for sensitive loads in autonomous mode. Indeed, DGs should be maintained to ensure that the microgrid's voltage and frequency values are standardised. They should also be able to distribute active-reactive power appropriately to the load's power rating. In the islanded mode, compensation concerns such as harmonic-current sharing, voltage and frequency restoration, voltage-profile management, and reactive-power compensation must be considered [10-11]. As a result, a flexible control approach based on inverter-based VSIs should be designed to fulfil all power-quality demands during the island mode.

II. VOLTAGE CONTROL TECHNIQUES FOR ISLANDED MICROGRID

Because distributed cooperative control approaches are more dependable and adaptable, they are gaining popularity in microgrid secondary control. Traditional techniques, on the other hand, rely on periodic communication, which is neither cost-effective nor efficient due to the high communication burden. An event-triggered method based distributed control technique is utilised to deal with secondary frequency and voltage management in the islanded microgrid, according to the author [1]. The proposed control strategies only require communication between distributed secondary controllers at some specific instants while having frequency and voltage restoration function and accurate active power sharing by using the outputs of estimators, which are reset to the actual values only at the event-triggered time, to replace the actual values in the feedback control laws. This approach [1] also examines the stability and inter-event interval. PSCAD/EMTDC includes an islanded microgrid test system for validating the suggested control methods. It is demonstrated that the suggested secondary control techniques, which are based on an event-triggered approach, may significantly minimize inter-agent communication.

This technique [1] addresses the distributed cooperative secondary restoration problem of the islanded microgrid utilizing an event-triggered control mechanism.

1) Voltage and frequency can be restored to nominal values while active power sharing remains accurate.
2) The communication load between the DGs' secondary controllers is greatly decreased.
3) The defined event-triggered time for each DG, based on decentralized event triggering mechanisms, may make the distributed control system stable while avoiding Zeno behavior.

Furthermore, because microgrid control may be implemented on a network with a high packet-drop rate, the influence of packet loss on event-triggered control performance will be investigated in the future. Meanwhile, sophisticated control methods such as finite-time control can be used with event-triggered communication to improve the secondary controllers' reaction time.

The construction of a robust model predictive controller for grid voltage management of an islanded microgrid was given by author [2]. A microgrid is created by connecting many dispersed generating units in tandem. The load's unpredictable and unknown nature results in unmodeled dynamics. This unmodeled dynamic introduces the observable influence of the microgrid's performance. The controller's design goal is to manage grid voltage in response to various types of loads.

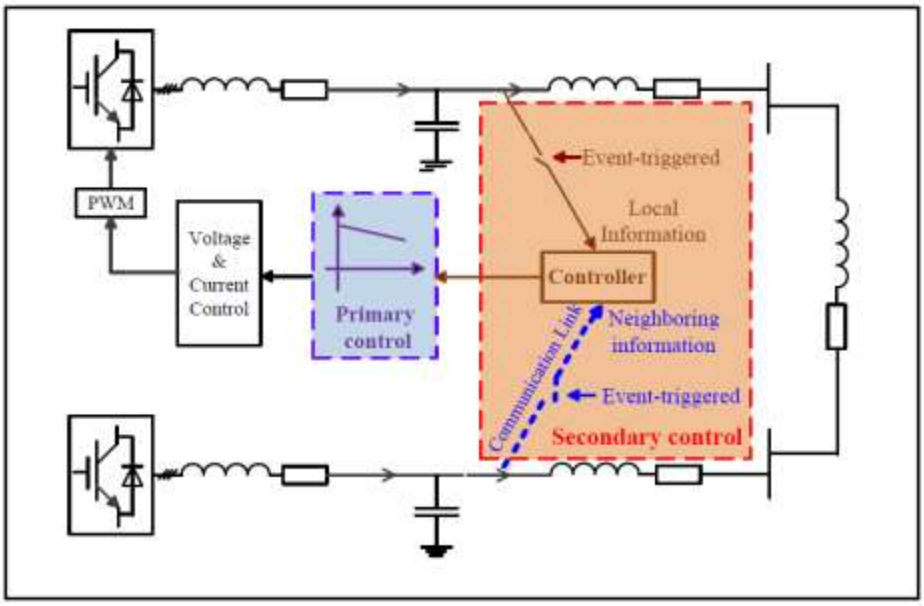

Fig.1. Schematic view of the proposed control structure [1]

The discrete valued function is used to construct this controller, which provides broad microgrid tracking performance. MATLAB/Simulink SimPower Systems are used to test the efficacy of the proposed controller. The simulation results demonstrate that the suggested controller has excellent tracking performance for microgrid voltage control.

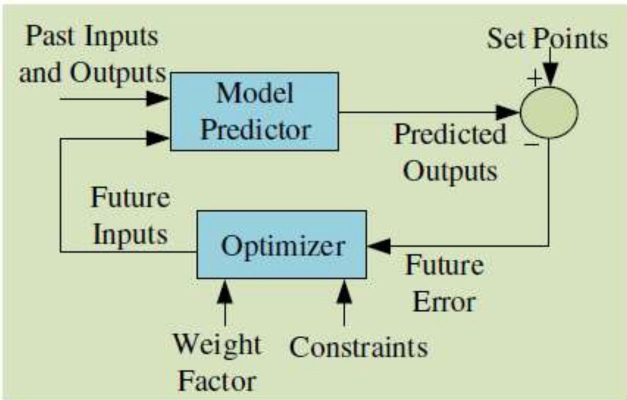

Fig.2. Control structure of Model Predictive Controller [2]

This technique for voltage oscillation management in an islanded microgrid presents the construction of a resilient discrete-valued model predictive controller. The controller is intended for use in a single-phase microgrid. This controller's performance is evaluated in a variety of circumstances. This controller ensures that the microgrid performs reliably under a variety of load dynamics and has a good tracking performance.

In islanded microgrids, this paper offers a cooperative secondary voltage control strategy, which may be thought of as multi-agent systems with dispersed generators acting as agents. As a result, utilizing a directed communication graph, the voltage variation produced by the primary control level may be corrected autonomously in a microgrid. The feedback control law is dealt with by an auxiliary centralized event triggered controller. For feedback control, agents' estimations are utilized instead of their real values in this method. The auxiliary centralised controller sends the same event-triggered time to all agents. As a result, communication between agents is only required when events occur, greatly reducing the strain on the communication network and improving the control structure's reliability. Here's where you'll find the stability analysis. To evaluate the efficacy of the suggested control method, simulation results based on an islanded microgrid test system in PSCAD/EMTDC are presented.

A cooperative secondary voltage control approach for an islanded microgrid based on MAS and a directed communication network was presented by the author [3]. State estimates are used to replace their continuous actual values in an event-driven manner. As a result, the suggested approach's major benefit is a significant reduction in the communication load between DGs as compared to the previous method. The suggested centralised event trigger function ensures that the system is stable and that the intervening interval is lower constrained from zero. It is demonstrated that the suggested control technique effectively maintains the islanded microgrid's voltages at the reference value.

With an additive kind of noise, the author suggested [4] an unique distributed noise resilient secondary control for voltage and frequency restoration of islanded microgrid inverter-based distributed generations (DGs). Existing distributed techniques are frequently built as secondary control system systems that assume perfect communication networks among DGs. The channels, on the other hand, are susceptible to stochastic noise, whilst each DG gets noisy measurements of its neighbours' states via ambient disturbances.

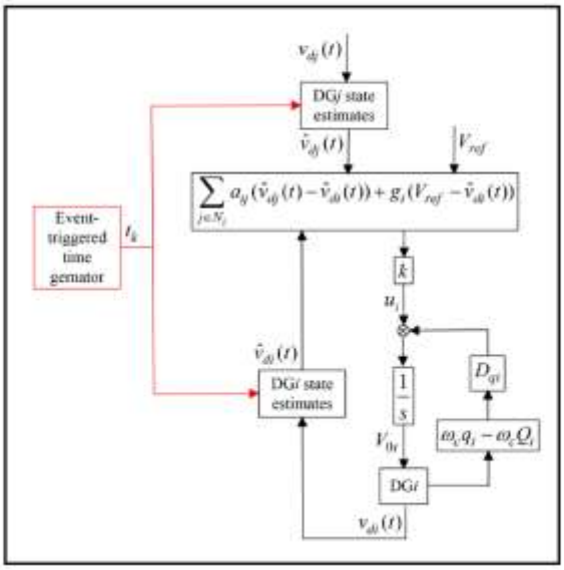

Fig.3. Block diagram of the proposed secondary voltage controller [3]

Existing distributed noise-resilient techniques do not consider the entire system model. This method, on the other hand, proposes consensus protocols that account for both noisy measurements and the system's complete nonlinear model, investigates the mean square average consensus for voltage and frequency restoration of islanded AC microgrids in an uncertain environment, and provides accurate proportional real power sharing. The state feedback of the agent and the relative states of the DG and its adjacent DGs are two components of our suggested consensus procedure. Finally, simulation studies in MATLAB/SimPower Systems are used to assess the control rules' performance. The suggested method's efficacy in controlling microgrid voltage and frequency and delivering accurate proportional actual power sharing is demonstrated by simulation results and comparisons with prior work.

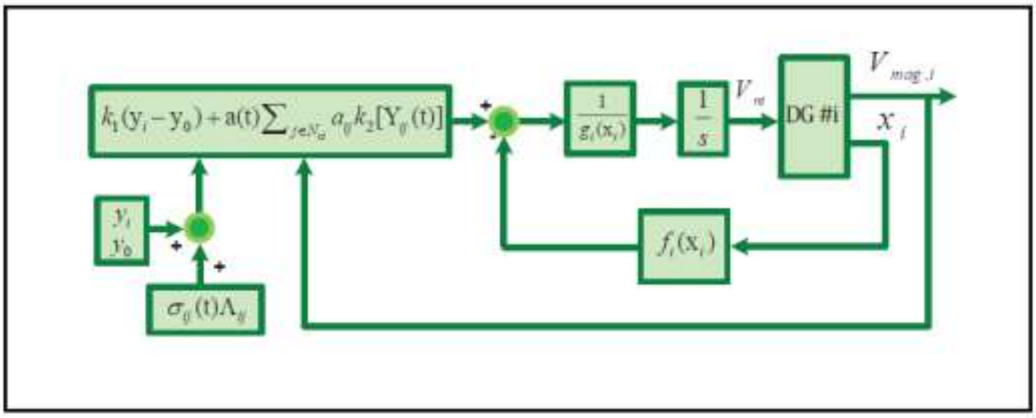

Fig.4. Block diagram of the distributed noise-resilient secondary voltage control [4]

Due to the presence of stochastic noise in communication lines, local controllers get noisy measurements from adjacent units. We took into account not just the noisy data, but also the entire nonlinear dynamic large-signal model of the microgrid system in the suggested consensus procedures. In an unpredictable environment, we offer a mean-square average-consensus model to manage microgrid voltage and frequency and give proportionate accurate actual power sharing.

Based on offline time-domain simulations in the MATLAB/Simulink environment, this method was presented [4] theoretical concepts, including mathematical modelling of microgrid, basic theorems, and design procedure of the proposed distributed noise resilient secondary controller, and evaluated the performance of the controller for small and large-signal disturbances. By comparing our findings to a previously published distributed secondary control technique, we were able to confirm our findings.

The results show that when faced with minor and large-signal disruptions, the suggested resilient control strategy allows the microgrid to recover voltage and frequency variations and retain stability. In the face of changes in the communication network architecture and communication uncertainty, this method performs well.

Finally, while the proposed secondary controller does not worsen the reactive power sharing among the DGs before applying the secondary control, the problem of proportional active/ reactive power sharing is completely resolved by adding virtual impedance to the complete dynamic of the primary control level.

[5], an unique distributed secondary control technique for both voltage and frequency regulation in islanded microgrids, was given by the author. To begin, the inverter-interfaced distributed generation (DG) large-signal dynamic model is expressed as a multi-input multi-output nonlinear system that may be partially linearized via input-output feedback linearization. The linear-distributed model predictive controller is then assigned in each DG to accomplish secondary voltage regulation by integrating the anticipated behaviors of nearby DG units.

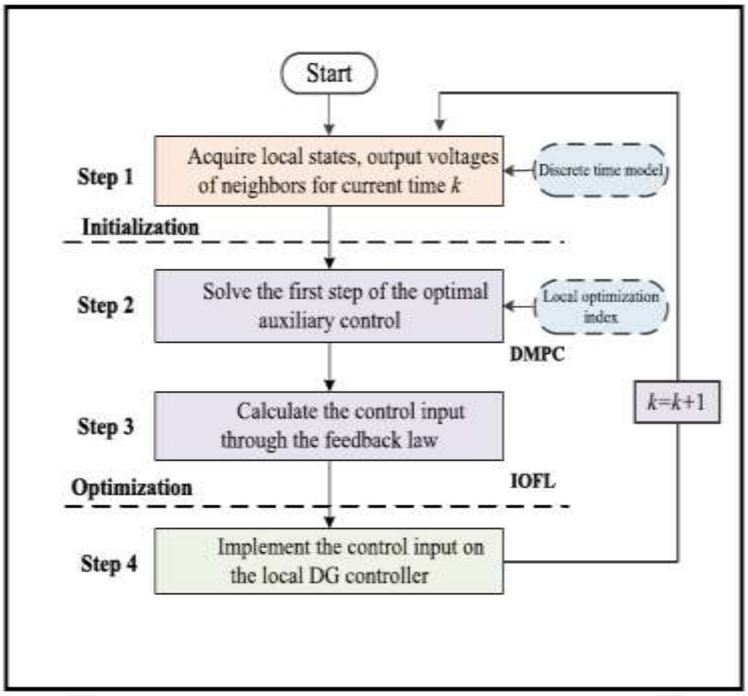

Fig.5. The routine process of IOFL-based DMPC algorithm [5]

A completely distributed secondary control technique is presented in this method [5] for voltage and frequency management as well as accurate active power sharing. The nonlinear dynamics of inverter-based DG may be converted into linear form using IOFL. The secondary voltage regulation is then accomplished using linear DMPC, utilising the predictive intelligence of nearby and local DGs. Frequency restoration and precise active power sharing are achieved via a distributed proportional integral method. Simulations are provided to verify the efficacy of the proposed secondary control under various operating situations, such as load disturbances, communication connection uncertainties, system characteristics, and time delays.

The design of a high-performance second-order controller for voltage regulation of a single- and three-phase islanded microgrid under various loads and fault circumstances was given by the author [6]. The microgrid is made up of a number of distributed generating units as well as local loads. The fluctuating nature of microgrid performance is due to the load being parametrically unknown and unpredictable. In the face of un-modeled loads, dynamic loads, harmonic loads, balanced, and unbalanced loads, the controller is designed to ensure robust performance. The results of a robust negative imaginary method are used to construct the controller.

The design of a second-order controller to regulate the load voltage of a single-phase and three-phase islanded MG system was proposed by the author [6]. The controller's design is explained using rigorous NI control theory. The suggested SISO and MIMO controllers achieve 150 and 65 dB voltage oscillation damping, respectively, when used with the MG system, ensuring rapid and safe operation of both single-phase and three-phase MG systems. The suggested controller's efficacy is also confirmed by comparing results to MPC and LQR. The comparative findings demonstrate that the proposed controller is almost two and three times quicker than MPC and LQR, and that it is stable even when plant dynamics vary by 25%, demonstrating the proposed controller's resilience.

The implementation of a fractional order PID (FOPID) controller into a single phase islanded microgrid with a single power source to regulate the variations in its output voltage is one of the techniques [7]. The proposed controller is adaptable in design since it has more tuning settings than an integer Order PID controller (IOPID). The Nelder-Mead optimization approach is used to create the proposed controller. The use of the optimization approach improves the system's performance. The controller is used in the system under various load conditions and uncertainties. Following a performance evaluation, it was discovered that using the proposed controller may reduce system voltage fluctuations and provide rapid response with reliable performance.

The design of a fractional-order PID controller for a single phase islanded microgrid system that works on a single energy source is presented in this article. The application of FOPID to the microgrid system demonstrates that the provided controller ensures that the microgrid system operates quickly, reliably, and precisely.

Author [8] suggested the secondary voltage control problem of an inverter-based islanded microgrid (MG). The dynamics of distributed generation (DG) under main control are first investigated and modelled. The voltage variation produced by main control is then eliminated using an RBF-neural-network (RBF-NN) sliding-mode controller. All DGs' output voltage may be restored to a reference value and is stable. Finally, using an MG with four DGs as an example, the experimental findings show that the secondary control method is effective.

The secondary regulation of the MG voltage is designed in one of the techniques [10]. The distributed control structure has a simpler communication network than the typical centralized control structure and prevents single points of failure. Without a centralized control unit, communication information is sent from one DG to the next through nearby DGs. The voltage restoration problem is solved using the RBF-NN sliding-mode control method in the secondary controller architecture.

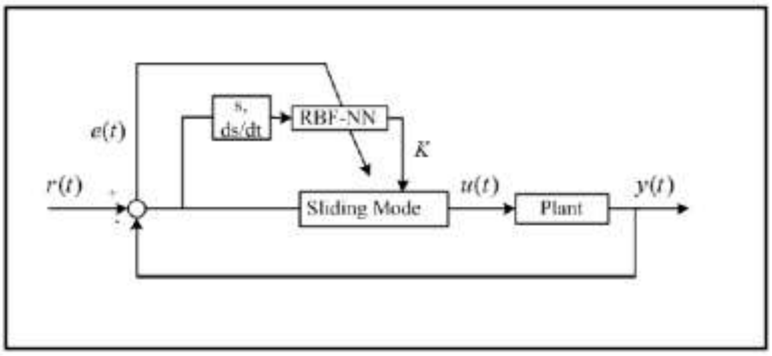

Fig.6. RBF-NN sliding-mode secondary voltage controller [8]

Chatter may be caused by simple sliding mode control, which is weakened by neural network theory. The simulation confirms the algorithm's efficacy and adaptability for MG's secondary voltage regulation, and the controller settings are adjusted to reach the desired system reaction speed. In fact, there is no way to eliminate communication delays and interference in the MG system. As a result, we will simulate the MG system in future research, taking into account time delays and noise disturbances in communication connections. In addition, the robust distributed control technique for the MG model that approximates the actual will be explored and constructed.

Thousands of sensors and a huge number of programmable devices, such as flexible loads, batteries, and distributed generators, are included in distribution networks, which might have an arbitrary configuration that is parametrically uncertain or topologically unknown. For an islanded microgrid, this work presents a new resilient non-linear voltage-control technique based on backstepping and fractional-order (FO) sliding mode control (SMC) (MG). The particle swarm optimization technique is then utilised to solve the challenge of selecting the controller settings. The major goal of this research is to improve the closed-loop control system's robust performance and disturbance rejection. This method [9] proposes a FO back-stepping SMC. In the presence of parametric uncertainties, un-modeled dynamics, unbalanced and non-linear loads with harmonics, the suggested controller reliably manages the MG voltages. Finally, the suggested technique's effectiveness in an islanded MG is examined under disturbance. To emphasise the benefits of the suggested controller, an in-depth comparison analysis is conducted. The overall harmonic distortion and output voltage steady-state error were successfully reduced, while dynamic performance and perturbation rejection capacity were effectively enhanced, according to simulation findings.

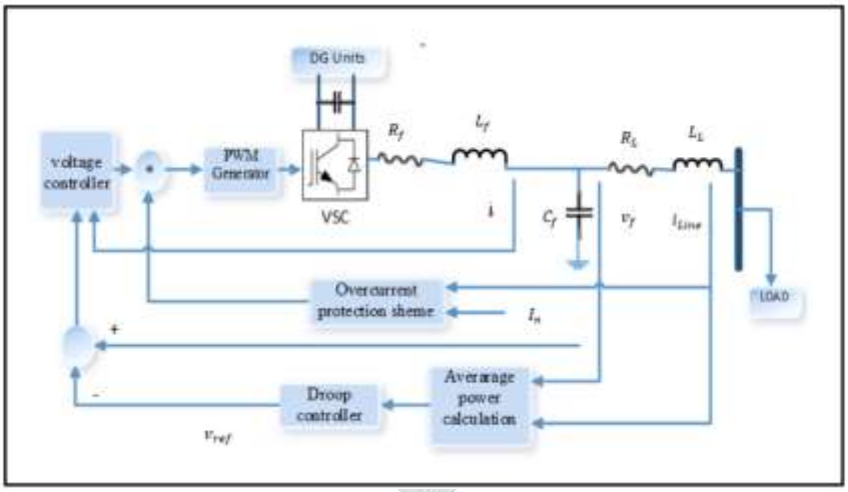

Fig.7. Schematic diagram control of VSC [9]

A parallel hybrid MG consisting of a PV power production system and a BESS is examined, controlled, and simulated in the MATLAB/Simulink environment, as recommended by the author [9]. The use of a novel extension of Lyapunov theory for the FO system is used to demonstrate a durable non-linear voltage controller for parallel VSC working in islanded.

The present secondary control is insufficient to cope with robustness and rapid response due to the intermittent nature of dispersed generation and unpredictability in load behaviour. A resilient nonlinear distributed secondary voltage controller is suggested to provide rapid compensation for the islanded microgrid [10], approached from a cooperative based control perspective influenced by the tracking consistency paradigm.The suggested control approach can achieve a compromise between the competing aims of voltage regulation and reactive power sharing by using sparse communication. Because the distributed design only needs information from its own and its neighbours, centralised controllers may be eliminated, allowing the system's flexibility and scalability to be increased. Finally, the simulation results and stability analysis are shown to evaluate control performance under fast load changes, robustness under communication failure, and flexibility during plug-and-play operation.

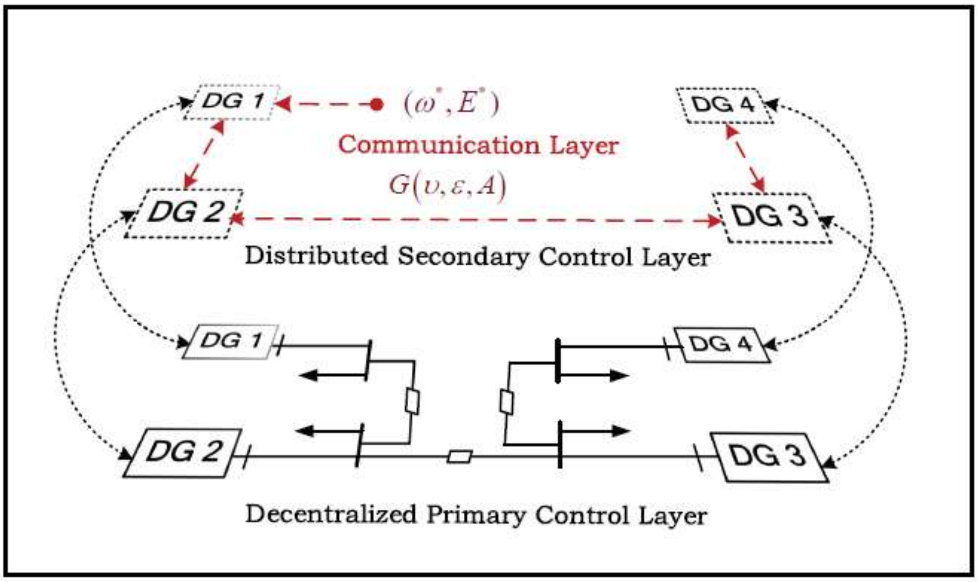

Fig.8. The architecture of the proposed DCSM secondary control for islanded microgrids [10]

Author [11] suggested a unique nonlinear distributed secondary voltage controller called DCSM for islanded microgrids. The DCSM controller has a high level of resilience and quick reaction, allowing it to cope effectively with the unpredictability and uncertainty of DGs and loads. The enhanced DCSM controller significantly boosted system adaptability and achieved a balance between the competing aims of voltage regulation and reactive power sharing, thanks to the consistency algorithm under sparse communication.

To validate the enhanced performances of the proposed DCSM controller, a series of simulation experiments are carried out in MATLAB/Simulink. As a consequence of the simulation,

(1) During load changes, the DCSM controller can more quickly reconcile competing goals while maintaining high performance.

(2) The controller has great resilience in the event of communication loss.

(3) Despite the loss of DG3, the bus voltages and frequencies are properly controlled, demonstrating the versatility of the plug-and-play procedure.

Because open communication techniques are widely used in distributed secondary control of islanded microgrids (MGs), the impact of the communication network and time delays on system performance cannot be overlooked. This approach [11] provides an ideal design for a directed communication topology and pinning location through the mirror operation and global propagation rates, respectively, based on the link between convergence and algebraic connectedness. Alternatively, to explore the delay-dependent stability of an MG system in terms of the controller, network, and pinning conditions, a small-signal dynamic model of an MG equipped with time-delayed distributed secondary voltage regulation is constructed. The individual delay margins with regard to distinct sets of controller gains and pinning are then calculated using an analytical procedure. The qualitative impacts of controller settings and pinning conditions on delay margins may be utilised to influence the design of both controllers and pinning for enhanced system performance through a series of trials.

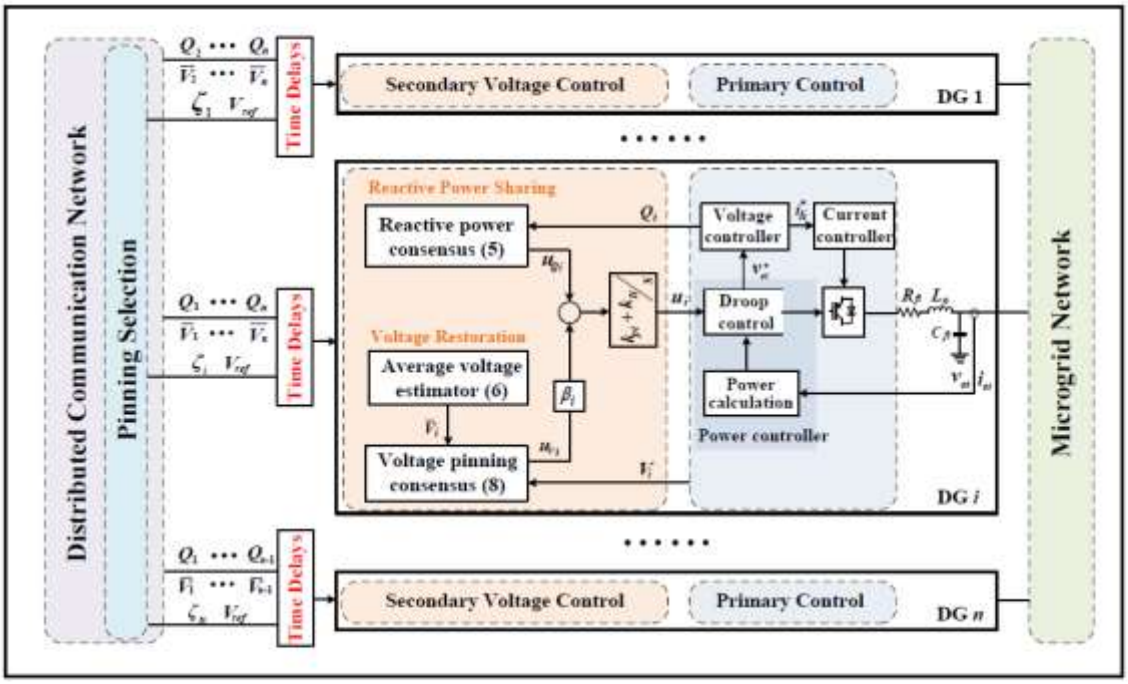

Fig..9. Block diagram of hierarchical control structure of islanded MGs [11]

First, the mirror operation and global propagation rates propose the optimal design schemes for directed network topology and pinning location based on the relationship between network algebraic connectivity and convergence, which outperforms existing approaches in terms of efficiency and adaptability. Then, in order to investigate the delay-dependent stability of MGs, a small signal dynamic model of an MG embedded with various time delays is created, and the delay margins corresponding to various controller and pinning circumstances may be calculated. The delay margin may be used as an indication to help designers of controllers and pinning conditions reach a balance between dynamic performance and delay-relevant resilience in MGs, thanks to the deduced effects of controller gains and pinning on delay margin.

III. CONCLUSION

Microgrids are increasingly being used in electricity distribution networks for economic, technological, and environmental reasons. However, the growing interest in microgrids for pooling renewable energy resources poses a significant challenge in terms of dependable operation and control. The paper's major objective is to examine the most recent primary control approaches and classify various power-sharing methods depending on whether or not the power-sharing unit uses the idea. A case-study simulation was carried out to evaluate the microgrid's operation in the islanding mode. The most important conclusion obtained from this simulation is that microgrids improve distribution system reliability by supplying electricity for sensitive loads even when the main grid is unavailable.

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